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Elite Kenyan Endurance Runners are Hydrated Day-To-Day with *Ad Libitum* Fluid Intake

BARRY W. FUDGE^{1,2}, CHRIS EASTON^{1,2}, DAVID KINGSMORE^{1,3}, FESTUS K. KIPLAMAI^{1,4}, VINCENT O. ONYWERA^{1,4}, KLAAS R. WESTERTERP^{1,5}, BENGT KAYSER^{1,6}, TIMOTHY D. NOAKES^{1,7}, and YANNIS P. PITSILADIS^{1,2}

¹International Centre for East African Running Science (ICEARS); ²Institute of Biomedical & Life Sciences (IBLS), University of Glasgow, Glasgow, UNITED KINGDOM; ³Department of Surgery, Gartnavel General Hospital, Glasgow, UNITED KINGDOM; ⁴Department of Exercise and Sports Science, Kenyatta University, Nairobi, KENYA; ⁵Department of Human Biology, Maastricht University, Maastricht, THE NETHERLANDS; ⁶School of Physical Education and Sports, Institute of Movement Sciences and Sports Medicine, Faculty of Medicine, University of Geneva, SWITZERLAND; and ⁷UCT/MRC Research Unit for Exercise Science and Sports Medicine, Department of Human Biology, University of Cape Town and Sports Science Institute of South Africa, Newlands, SOUTH AFRICA

ABSTRACT

FUDGE, B. W., C. EASTON, D. KINGSMORE, F. K. KIPLAMAI, V. O. ONYWERA, K. R. WESTERTERP, B. KAYSER, T. D. NOAKES, and Y. P. PITSILADIS. Elite Kenyan Endurance Runners are Hydrated Day-To-Day with *Ad Libitum* Fluid Intake. *Med. Sci. Sports Exerc.*, Vol. 40, No. 6, pp. 1171–1179, 2008. Previous studies of elite Kenyan endurance runners reported that athletes did not consume liquids before or during training and infrequently consumed modest amounts of liquids after training that contributed to low daily fluid intake. **Purpose:** To assess hydration status of elite Kenyan endurance runners during an important training period. **Methods:** Hydration status was monitored in fourteen elite Kenyan endurance runners over a 5-d training period 1 wk prior to the Kenyan national trials for the 2005 IAAF Athletics World Championships by measuring body mass, urine osmolality, total body water, and daily fluid intake. Dietary sodium (Na) intake was estimated using a 5-d nutritional diary and biochemical analysis, whilst [Na] was determined in urine and sweat. Intestinal temperature was monitored continuously during training sessions. **Results:** Daily fluid intake was consistent with previous observations. There was a significant body mass loss during the morning, interval, and afternoon training sessions ($P < 0.05$). Nevertheless, mean total body water and pretraining body mass were well maintained day-to-day throughout the 5-d recording period ($P = 0.194$ and $P = 0.302$, respectively). Furthermore, there was no significant difference between the osmolality of the morning urine sample and the evening sample ($P = 0.685$). Mean Na intake was not significantly different to Na loss in sweat and urine ($P = 0.975$). No athlete showed signs or symptoms of heat strain at any time. **Conclusions:** These results demonstrate that elite Kenyan endurance runners remain well hydrated day-to-day with an *ad libitum* fluid intake; a pattern and volume of fluid intake that is consistent with previous observations of elite Kenyan endurance runners. **Key Words:** DIET COMPOSITION, SWEAT RATE AND COMPOSITION, URINE OSMOLALITY, ELITE KENYAN RUNNERS

Kenya has enjoyed increasing success in international racing over the last four decades since its emergence in world athletics in the 1960s. For example, in 2004, the majority (51%) of top ten yearly performances from 800 m to marathon were from male Kenyan athletes. Considering the success of these runners and the importance of diet and lifestyle for optimum endurance

running performance (3), the diet and lifestyle practices of this unique group of runners warrant examination. Two recent investigations (17,30) reporting the nutritional and lifestyle practices of elite Kenyan endurance runners whilst preparing for major competition (Kenyan National Championships 2003 and Athens Olympic games 2004 national trials, respectively) found athletes did not consume fluids before or during training, and only infrequently consumed modest amounts of fluids immediately after training. This contributed to low daily fluid intake, mainly water (1.1 ± 0.3 ; 0.9 ± 0.5 L·d⁻¹, from references 30 and 17, respectively) and milky tea (1.2 ± 0.3 ; 0.9 ± 0.3 L·d⁻¹, respectively). These fluid intake and drinking habits were substantially less than previous recommendations of the American College of Sports Medicine (ACSM) (10), which were 0.4–0.6 L of fluid 2–3 h before exercise, 0.6–1.2 L·h⁻¹ while exercising, aiming at total replacement of all fluid lost during exercise, or at least up to the maximal amount tolerated; a pattern and volume of fluid replacement similar

Address for correspondence: Dr YP Pitsiladis, International Centre for East African Running Science (ICEARS), Institute of Biomedical & Life Sciences, West Medical Building, University of Glasgow, Glasgow, G12 8QQ, UK; E-mail: Y.Pitsiladis@bio.gla.ac.uk.

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to that recommended by the National Association of Athletic Trainers (NAAT) (5), and the US Army (25). The drinking behaviours (i.e., *ad libitum*) reported previously in elite Kenyan endurance runners (17,30) are consistent with empirical observations that elite athletes typically do not adhere to prevailing fluid intake recommendations (for a review, see reference (9)). Recently, the ACSM has replaced their prior Position Stand (10) with an updated one on exercise and fluid replacement (4) that advocates drinking *ad libitum* ($0.4\text{--}0.8\text{ L}\cdot\text{h}^{-1}$) during exercise (with the lower value for slower lighter individuals competing in cooler environments, and the higher value for faster larger individuals competing in warmer environments) in order to prevent excessive dehydration (i.e., $< 2\%$ body mass loss), and only aggressively ingest fluid and electrolytes before/after exercise if time does not permit consumption of normal meals and beverages to replace exercise induced fluid and electrolyte losses. These new recommendations (4) appear to be more in keeping with previous observations of elite Kenyan endurance runners (17,30). However, their hydration status day-to-day during an important training period remains to be determined.

Therefore, the main aim of the present investigation was to assess the hydration status of elite Kenyan endurance runners during an important training period given their previously reported drinking behaviors (17,30) that appear more in line with recent recommendations (4). This investigation also provides a rare insight into the lifestyle, training and nutritional practices of some of the most successful endurance runners in the world 1 wk prior to major competition.

METHODS

Subjects. Fourteen elite Kenyan endurance runners (range of athletic discipline: 800 m to marathon) were invited to participate in this study (Table 1A). All athletes gave their written informed consent prior to participating in the study. The experimental procedures were in accordance with the Helsinki declaration and were approved by the local ethics committee at Kenyatta University, Nairobi, Kenya. The athletes were highly trained and included World, Olympic and Junior Champions frequently competing in major national and international middle- and long-distance running events. Athletes were based at a high altitude training camp (Global Sports Training Camp, Kaptagat, Eldoret, Kenya) situated in the North Rift Valley (altitude: 2400 m a.s.l., daytime ambient temperature: $8\text{--}24^\circ\text{C}$, RH: $31\text{--}100\%$) and were all heat and altitude acclimatised at the time of testing. The athletes were in a 10-d taper phase of their training cycle as the investigation was undertaken 1 wk prior to the Kenyan national trials for the 2005 IAAF Athletics World Championships.

Experimental design. Subjects were monitored for a period of 5 training days during the course of a standard training wk prior to major competition. Organized training

TABLE 1. A Physical and anthropometric characteristics of elite Kenyan endurance runners ($n = 14$). B. Sweat electrolyte concentration during training sessions calculated from four collection sites and 24-h urinary losses ($n = 9$). Mean \pm SD is shown.

	Mean	SD
A		
Age (yr)	22	3
Height (cm)	170	5
Body mass (kg)	54.8	6.3
Body mass index ($\text{kg}\cdot\text{m}^{-2}$)	19	2
A_D (m^2)	1.6	0.1
$A_D\cdot\text{kg}^{-1}$ ($\text{cm}^2\cdot\text{kg}^{-1}$)	300	19
Body fat (%)	7.5	1.4
B		
Sweat [Na] ($\text{mmol}\cdot\text{L}^{-1}$)	37.0	8.0
Sweat [K] ($\text{mmol}\cdot\text{L}^{-1}$)	4.6	1.1
Urine Na loss ($\text{g}\cdot\text{d}^{-1}$)	2.3	1.2
Urine K loss ($\text{g}\cdot\text{d}^{-1}$)	2.1	0.9

Key: body surface area (A_D); Surface area to mass ratio ($A_D\cdot\text{kg}^{-1}$); Sodium (Na); Potassium (K).

runs were carried out mostly in groups that were influenced by athletic discipline and instructions from coach/manager. Training schedules typically incorporated up to two variable distance-training sessions per day (i.e., a morning run and a noncompulsory afternoon run) and two interval-training sessions per week (i.e., midmorning run).

Procedures and protocols. Body water compartments, urine osmolality and specific gravity, body mass, and body fat were measured each morning as follows. Body water compartments were estimated using a multifrequency bioimpedance analyser (Bodystat Multiscan 5000 Bioimpedance analyser, Bodystat Ltd, Isle of Man). Multifrequency bioimpedance allows total body water and extracellular water to be estimated; from these measurements intracellular water can also be deduced (39). The multifrequency bioimpedance measurements were taken after the subjects woke while they lay comfortably in a supine position for at least 10 min on a nonconductive surface with their arms and legs slightly abducted, ensuring consistent distribution of body water. Following this, subjects were asked to supply a 20-mL urine sample, which was analysed for osmolality by freezing point depression (Micro-osmometer 3300, Vitech Scientific, West Sussex, UK) and specific gravity (Combur test strips, Roche Diagnostics, East Sussex, UK) within 15 min to give an index of pretraining hydration status (36); subjects also provided a 20-mL urine sample before going to sleep each night. Body mass and percent body fat measurements were then made simultaneously after subjects had voided and before the consumption of any food or fluid using a leg-leg bioimpedance system equipped with a digital scale (Tanita Body Fat Analyzer, TBF 521, Tanita Corporation of America, Inc., Arlington Heights, IL). The estimates of percent body fat provided by the manufacturer's software were reported (the prediction equation used by the Tanita system is not disclosed by the manufacturer so the equation used cannot be presented). Although the leg-leg bioimpedance system has been shown to reliably measure percent body fat in males when compared to underwater

weighing (7), validation studies have not been carried out in this specific population.

Prior to the morning training session on the first day of the 5-d investigative period, height was recorded using a wall mounted stadiometer. Body surface area (A_D) was calculated from body mass and height as described by (12); following this, surface area to mass ratio ($A_D \cdot \text{kg}^{-1}$) was also calculated.

An HR monitor (Suunto t6, Suunto Oy, Vantaa, Finland) was attached to record HR continuously throughout each training run. The peak HR (HR_{Peak}) was considered the highest achieved HR in all training sessions completed by individual subjects throughout the recording period. Intestinal temperature (T_i) was monitored using a telemetric pill system (CorTemp, HQ inc., Palmetto, Florida, USA) that subjects consumed 8–10 h before the morning run (13). T_i was recorded continuously during the exercise period on the CorTemp™ receiver that was secured to the small of the subject's back in a neoprene running pack (Hybrid music pak, NATHAN Human Propulsion Laboratories, Philadelphia, USA). The Timex® Bodylink™ system (Timex Corporation, Middlebury, CT, USA) was used to determine the distance, time and running speed of the training runs by utilizing Global Positioning System (GPS) technology. Athletes wore the Timex® Performance device during individual and group runs. HR, T_i , and Timex® data were recorded during all training sessions throughout the study period. Body mass was measured before and after each training session. Sweat loss and sweat rate were calculated from the change in body mass (the relatively small changes in body mass due to substrate oxidation and other sources of water loss were ignored). RPE (6) was reported at the end of each training run. Environmental conditions (i.e., ambient temperature (T_a) and RH) were recorded (C8600 10-channel microprocessor, Comark, Hertfordshire, UK) each morning and before and after every training session.

The dietary intake of ten subjects was measured daily during the 5-d investigative period. While at the training camp, meals and snacks were served at standard times each day: breakfast (08:00), midmorning snack (10:00), lunch (13:00), afternoon snack (16:00), and dinner (19:00). Athletes selected their portion sizes *ad libitum* from the provided food. Samples of all foods and fluids consumed were chemically analysed (Food Industrial Research and Technological Development Company S.A., Athens, Greece) for energy (calculated by Atwater energy factors (24)), carbohydrate (calculated 'by difference', i.e., carbohydrate = 100 – fat – proteins – moisture – ash), fat (measured by petroleum ether extraction according to the Soxhlet method (18)), protein (calculated from analysis by Kjeldahl titration method (18)), moisture (determined by oven drying the sample at 105°C for 4 h (18)), and sodium (Na) and potassium (K) content (both analysed by flame photometry). During the study period, subjects were required to weigh and record all food and drink consumed; individual digital weighing scales readable to 1 g were used. All food items were weighed before and after cooking and cooking

method noted. Subjects were also required to continue weighing all food and drink when away from the camp (e.g., athletes occasionally walked to the local shop for snacks between training runs); samples of any food or drinks consumed were collected for chemical analysis. The weighed dietary intake data were used to determine energy intake and diet composition using results of the chemical analysis of foods. Metabolic water was determined by multiplying estimated energy expenditure by the fraction of energy in the diet from carbohydrate, protein, and fat (data derived from chemical analysis of foods). The oxidation of carbohydrate, protein and fat yields 0.60, 0.41, and 1.07 mL water·g⁻¹, respectively (16). Athletes did not receive any specific dietary recommendations from their coach/manager. One subject consumed a daily multivitamin.

Energy expenditure was assessed by physical activity ratio (2). Subjects were instructed to record in detail their individual activities each day (including type, intensity and duration of activity). The compendium of physical activities (2) was used to assign specific activities with their respective metabolic equivalent. The total energy cost is expressed as a multiple of basal metabolic rate (BMR). In the present study, BMR was calculated using the Schofield equation (35).

Nine of the ten subjects who recorded dietary intake during the 5-d investigative period also completed one 24-h urine collection. The urine volume was measured and mixed thoroughly before a representative 20-mL sample was analysed for osmolality and specific gravity (as described above) and [Na] and [K] by flame photometry (Flame Photometer Model 410, Corning, Halstead, Essex, UK). During the 24-h urine collection period sweat samples were also collected during all training sessions from four skin sites (chest, forearm, back, and thigh) by absorbent sweat patches applied to the skin surface (Tagaderm+Pad, 3M, Loughborough, UK). The gauze patches were covered with an adhesive nonporous film that held them in place and prevented evaporation of sweat. The patches were positioned before the start of each training session and remained in place throughout the session. All patches were placed on the right hand side of the body after preparation of the skin site by washing with deionised water and drying with a clean electrolyte-free gauze swab. The patches were removed after each training session and placed in sealed sterile containers until they were analysed. After weighing of the patches and elution of sweat with distilled water, the sweat collected was analysed for [Na] and [K] by flame photometry (as previously described). The [Na] and [K] were used to calculate total Na and K loss from sweat loss (i.e., body mass loss) during training runs. The total quantity of Na and K lost in the sweat and urine over the 24-h period was used to calculate an estimate of total Na and K lost from the body over the course of a single day and compared to the total Na and K intake of the diet assessed by chemical analysis of all food and fluids consumed during the 24-h period.

Data analysis. Data are expressed as the mean \pm SD or median (range) as appropriate following a test for the normality of distribution. Paired *t*-tests were used to compare body mass loss during training sessions, pretraining body mass in the morning vs preinterval training body mass, pretraining body mass in the morning vs pretraining body mass in the afternoon, preinterval training body mass vs pretraining body mass in the afternoon, initial body mass vs final body mass, energy intake vs energy expenditure, morning urine osmolality vs evening urine osmolality, morning urine specific gravity vs evening urine specific gravity, Na intake vs Na loss, and K intake vs loss. A one-way ANOVA for repeated measures was used to determine whether there was a significant difference in daily total body water, extracellular water and intracellular water compartments and body mass measured in the morning before training. Statistical significance was set at $P < 0.05$.

RESULTS

Environmental conditions. Environmental conditions (i.e., T_a and RH) during the morning (06:00), interval (09:00), and afternoon training sessions (15:00) were (mean \pm SD) $10.7 \pm 1.6^\circ\text{C}$ and $75 \pm 3\%$ RH, $17.9 \pm 1.1^\circ\text{C}$ and $68 \pm 4\%$ RH, and $21.1 \pm 2.1^\circ\text{C}$ and $43 \pm 11\%$ RH, respectively.

Body mass and fluid balance. No correction was required for food and fluid intake during training sessions as no fluid or food was consumed. On the days when urinary losses were not recorded, body mass was not corrected for any urinary losses during training runs. Any body mass losses due to fecal losses during training runs were not corrected for. On average there was a significant body mass loss during the short, medium and long morning training runs (0.5 ± 0.4 kg, $P < 0.001$; 0.8 ± 0.4 kg, $P < 0.001$; 1.1 ± 0.4 kg, $P < 0.001$) as well as interval (0.7 ± 0.3 kg; $P < 0.001$) and afternoon (0.5 ± 0.4 kg; $P < 0.001$) training runs. This was equivalent to 0.8 ± 0.5 , 1.5 ± 0.5 , 2.0 ± 0.7 , 1.3 ± 0.5 and $1.0 \pm 0.6\%$ body mass loss, respectively, and mean sweat rates of 1.0 ± 0.7 , 1.0 ± 0.4 , 0.8 ± 0.4 , 1.0 ± 0.4 and 0.9 ± 0.6 L·h⁻¹, respectively. Despite significant loss in body mass, athletes that completed a morning run and an afternoon run in the same day, had no significant difference between pretraining body mass in the morning and afternoon pretraining body mass (56.1 ± 4.4 kg vs 56.0 ± 4.0 kg; $P = 0.761$). In contrast, athletes that completed a morning run and an interval training session in the same day, commenced interval training with a significant loss in body mass (0.8 ± 0.5 kg; $P < 0.001$); postinterval training, athletes had a mean body mass deficit of 1.5 ± 0.6 kg, equivalent to $2.7 \pm 1.0\%$ body mass loss. Nevertheless, athletes that completed an interval training session and an afternoon run in the same day, had on average regained all water lost via sweating and more as evidenced by a significant positive difference between

pretraining body mass prior to interval training and afternoon pretraining body mass (53.5 ± 2.1 kg vs 54.1 ± 2.4 kg; $P = 0.007$). Similarly, athletes that completed a morning run, interval training and an afternoon run in the same day had no significant difference between pretraining body mass in the morning and afternoon pretraining body mass (53.9 ± 2.5 kg vs 53.6 ± 2.6 kg; $P = 0.400$). Mean total body water (31.4 ± 3.4 L; $P = 0.194$), extracellular water (14.2 ± 1.5 L; $P = 0.564$), intracellular water (17.1 ± 1.9 L; $P = 0.557$), and pretraining body mass (53.6 ± 6.8 kg; $P = 0.302$) were well maintained day-to-day throughout the investigative period. Mean osmolality and specific gravity of urine supplied by the athletes in the morning was not significantly different from the evening sample supplied before sleeping (osmolality: 522 ± 117 vs 505 ± 98 mOsmol·kg⁻¹, respectively; $P = 0.685$; specific gravity: 1.017 ± 0.004 vs 1.016 ± 0.004 , respectively; $P = 0.388$).

Energy balance, physical activity and diet composition. The reported energy intake assessed by chemical analysis of all food and fluids consumed was not significantly different from the estimated energy expenditure assessed by physical activity ratio (12.3 ± 1.5 MJ·d⁻¹ vs 13.6 ± 2.2 MJ·d⁻¹; $P = 0.154$; $n = 10$). Body mass on day 1 and day 5 did not differ significantly (55.9 ± 6.1 kg vs 55.6 ± 6.2 kg; $P = 0.167$; $n = 10$). Physical activity level was 2.1 ± 0.3 (energy expenditure/BMR). The diet consisted mainly of carbohydrate ($79.0 \pm 2.6\%$, 9.8 g·kg⁻¹ BM·d⁻¹) compared with protein ($14.3 \pm 2.1\%$, 1.8 g·kg⁻¹ BM·d⁻¹) and fat ($6.6 \pm 1.0\%$, 0.8 g·kg⁻¹ BM·d⁻¹).

Mean Na intake assessed by chemical analysis of all food and fluids consumed in a 24-h period was not significantly different from Na loss during the same 24-h period in sweat and urine assessed by 24-h urine and training run sweat patch analysis (3245 ± 901 vs 3254 ± 1070 mg·d⁻¹; $P = 0.975$; $n = 9$). In contrast, mean K intake was significantly different from K loss in sweat and urine (3812 ± 489 vs 2346 ± 846 mg·d⁻¹; $P < 0.001$; $n = 9$). All nine athletes completed a morning run (17.4 ± 2.8 km) with a further three completing an additional afternoon run (5.0 ± 1.0 km). Sweat electrolyte concentration obtained from the four collection sites and 24-h urinary losses are shown in Table 1B.

Daily fluid intake consisted mainly of water (0.7 ± 0.5 L·d⁻¹; 18.4%) and milky tea (1.2 ± 0.4 L·d⁻¹; 31.6%) with a small contribution from the intake of other fluids such as soft drinks and milk (0.4 ± 0.2 L·d⁻¹; 10.5%). Other sources of daily fluid intake were water consumed as moisture in food (1.0 ± 0.1 L·d⁻¹; 26.3%) and metabolic water production as a result of oxidation of carbohydrate, protein, and fat (0.5 ± 0.1 L·d⁻¹; 13.2%) resulting in a mean total daily fluid intake of 3.8 ± 0.8 L·d⁻¹. Mean osmolality of the tea regularly consumed by the athletes was 281 ± 55 mOsmol·kg⁻¹; composition of the tea was 0.2 MJ·100 g⁻¹ of energy, 1.0 , 0.2 and 8.28 g·100 g⁻¹ of protein, fat and carbohydrate, respectively, and 16.98 and 28.77 mmol·L⁻¹ of [Na] and [K], respectively.

Physiological response to running. Mean time, distance, speed, RPE, and % HR_{peak} for morning runs, interval training and afternoon runs is shown in Table 2. Training distance achieved over the 5-d recording period was 81.7 ± 11.3 km. Mean T_i and HR at 5 min intervals during morning and afternoon training sessions are shown in Figure 1. Average peak T_i during interval training was $39.5 \pm 1.8^\circ\text{C}$.

DISCUSSION

The main finding of the present investigation is that despite low daily fluid intake, elite Kenyan endurance runners remain well hydrated day-to-day during an important training period. The pattern and volume of fluid intake reported in the present study is consistent with previous observations of elite Kenyan endurance runners (17,30), and supports the principle of a daily *ad libitum* fluid and food intake strategy for elite Kenyan endurance runners during an important training period.

Fluid intake and hydration status. Body mass loss as a result of sweating during running was fairly modest during training runs. A contributing factor may have been the relatively low body mass of the subjects in the present study (Table 1A) that is similar to reported values of

African endurance runners but less than Caucasian endurance runners (e.g., (32)). In contrast, body fat (Table 1A) is similar to values reported in the literature for both African and Caucasian endurance runners (e.g., (32)). Epstein et al. (14) suggest that thermoregulation is more efficient the greater the A_D available for evaporation per unit of body mass; this is especially apparent when exercising in a hot dry environment. The $A_D \cdot \text{kg}^{-1}$ of the runners in the present study (Table 1A), is similar to values previously reported in Kenyan runners but greater than values reported in Caucasian endurance runners (e.g., (32)). Therefore, a low body mass index coupled to a high A_D may have resulted in the modest sweat losses observed, thus requiring relatively little fluid intake to compensate. In addition, mild ambient conditions and/or relatively low training duration/intensity (Table 2) may have also contributed to the modest fluid losses in the present investigation. Thus, sweat rate can be influenced by a number of factors, including meteorological variables (e.g., T_a , wind speed, humidity), exercise intensity, state of fitness, level of heat acclimation, and the amount of insulative clothing worn. Indeed, it was found that sweat rates were similar throughout all training sessions despite lower T_a during the morning run compared to the midmorning and afternoon runs ($10.7 \pm 1.6^\circ\text{C}$ vs $17.9 \pm 1.1^\circ\text{C}$ and $21.1 \pm 2.1^\circ\text{C}$, respectively). This is likely explained by athletes wearing insulative clothing during morning runs that resulted in a greater than expected sweat loss for the T_a experienced.

Despite relatively low body mass loss during training runs, athletes had greater losses during interval training ($2.7 \pm 1.0\%$ body mass) as a result of accumulating a deficit from the preceding morning run since athletes ingested no fluid before and during training and infrequent and modest amounts immediately after. However, these losses may still arguably be within a tolerable range for dehydration that will not negatively affect performance, especially in the mild T_a experienced by the runners during the present investigative period (23). Nevertheless, even though body mass loss was significant during training runs and irrespective of whether the elite Kenyan endurance runners had completed 1, 2, or 3 training sessions over the course of a training day, they remained on average well hydrated throughout each day of the 5-d recording period with no heat strain evident at any time during training sessions (Fig. 1). Maintenance of hydration balance over the 5-d recording period was evidenced by similar total body water and body mass values recorded each morning before training despite athletes incurring body mass deficits due to training runs. Daily hydration balance was further demonstrated by a similar pretraining body mass in the morning and pretraining body mass in the afternoon. It was also found that there was no significant difference in osmolality and specific gravity of the urine supplied by the athletes in the morning when compared to the evening sample. During the 5-d recording period, mean osmolality and specific gravity in the morning (519 ± 203 mOsmol $\cdot\text{kg}^{-1}$;

TABLE 2. Training load and physiological response to running during morning (i.e., AM), mid-morning (i.e., interval training) and afternoon (i.e., PM) training runs. Mean \pm SD is shown.

	Mean	SD
Short run—AM		
Time (min)	30.3	0.5
Distance (km)	6.4	0.5
Speed ($\text{km}\cdot\text{h}^{-1}$)	12.6	0.9
RPE (6–20)	10	2
% HR _{peak}	71	9
T_i ($^\circ\text{C}$)	37.2	0.4
Medium run—AM		
Time (min)	63.2	7.4
Distance (km)	14.0	1.5
Speed ($\text{km}\cdot\text{h}^{-1}$)	13.3	2.0
RPE (6–20)	13	2
% HR _{peak}	78	10
T_i ($^\circ\text{C}$)	37.3	0.4
Long run—AM		
Time (min)	63.6	5.4
Distance (km)	18.2	1.4
Speed ($\text{km}\cdot\text{h}^{-1}$)	17.2	1.6
RPE (6–20)	13	1
% HR _{peak}	81	7
T_i ($^\circ\text{C}$)	37.9	0.6
Interval training		
Time (min)	49.5	17.4
Distance (km)	5.6	2.1
Peak Speed ($\text{km}\cdot\text{h}^{-1}$)	25.7	2.3
RPE (6–20)	16	2
Peak % HR _{peak}	96	4
T_i ($^\circ\text{C}$)	37.9	0.5
Run—PM		
Time (min)	33.4	6.9
Distance (km)	5.9	1.1
Speed ($\text{km}\cdot\text{h}^{-1}$)	10.5	2.2
RPE (6–20)	9	2
% HR _{peak}	66	7
T_i ($^\circ\text{C}$)	37.6	0.5

Key: Rating of perceived exertion (RPE (arbitrary units 6–20)); Percentage of peak heart rate (% HR_{peak}); Intestinal temperature (T_i).

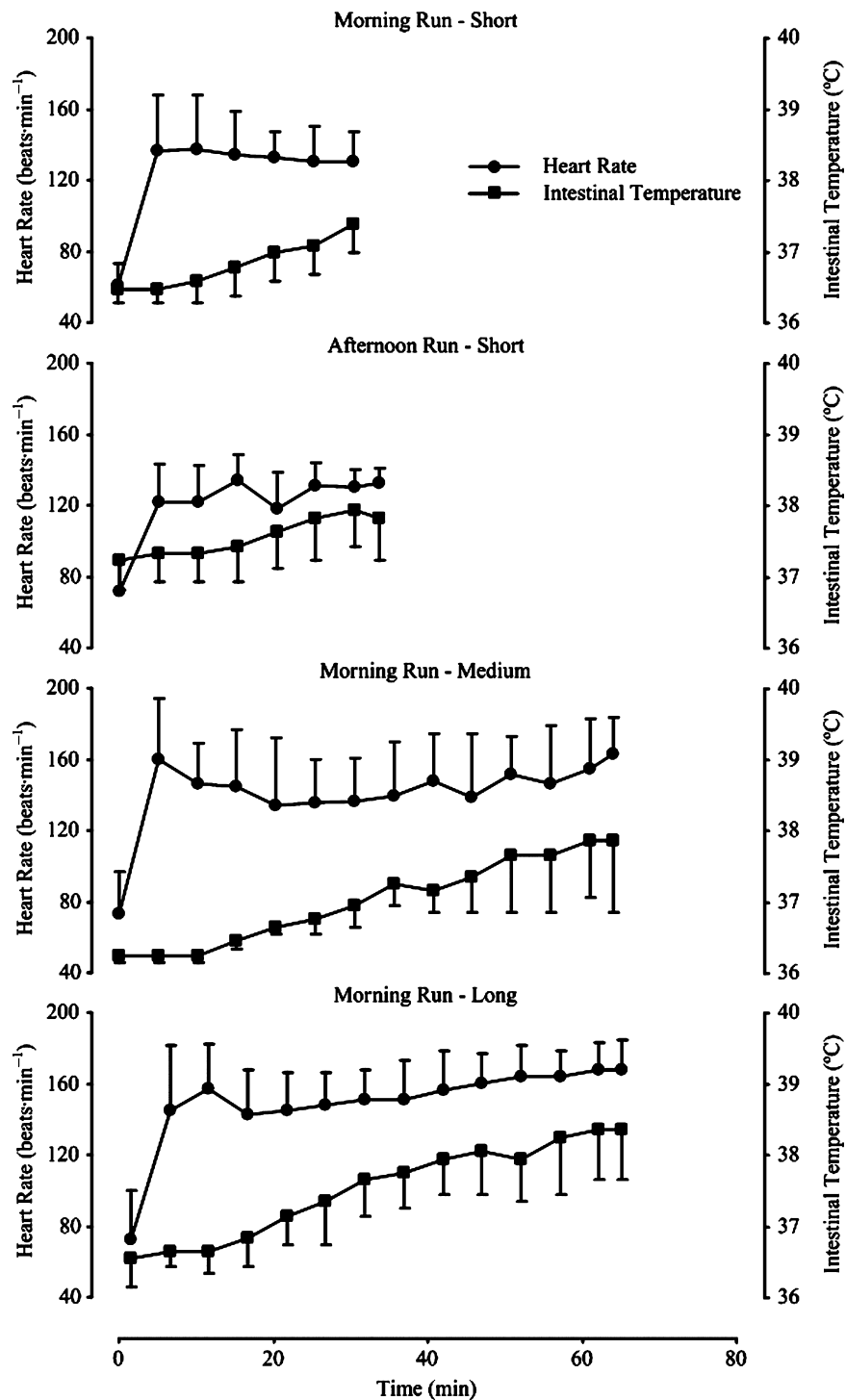


FIGURE 1—Mean intestinal temperature and heart rate at 5-min intervals for morning (short, medium, and long) and afternoon training runs.

1.017 ± 0.006 , respectively) and evening (502 ± 229 $\text{mOsmol}\cdot\text{kg}^{-1}$; 1.015 ± 0.007 , respectively) were below values suggested to correctly classify dehydration in individuals (i.e., > 700 $\text{mOsmol}\cdot\text{kg}^{-1}$ and a specific gravity = 1.020 (4)). Maintenance of hydration status, despite athletes losing body water during training, was achieved by water gained from the diet and fluid ingested throughout the day *ad*

libitum. The pattern and volume of fluid intake reported in the present study is consistent with previous observations of elite Kenyan endurance runners (17,30) as fluid intake consisted mainly of water (0.7 ± 0.5 $\text{L}\cdot\text{d}^{-1}$; 18.4%) and milky tea (1.2 ± 0.4 $\text{L}\cdot\text{d}^{-1}$; 31.6%) with a small contribution from the intake of other fluids such as soft drinks and milk (0.4 ± 0.2 $\text{L}\cdot\text{d}^{-1}$; 10.5%). Interestingly the mean osmolality

of the milky tea regularly consumed by the athletes was isotonic ($281 \pm 55 \text{ mOsmol}\cdot\text{kg}^{-1}$), high in energy ($0.2 \text{ MJ}\cdot 100 \text{ g}^{-1}$) and had a modest $[\text{Na}]$ ($16.98 \text{ mmol}\cdot\text{l}^{-1}$) that is similar to conventional sports drinks. Furthermore, Shirreffs et al. (37) found milk (a major constituent of the tea regularly consumed by the athletes) was effective at replacing sweat losses and maintaining euhydration following exercise induced dehydration (approximately 2% body mass loss). Other sources of daily fluid intake were water consumed as moisture in food and metabolic water production resulting in a mean total daily fluid intake of $3.8 \pm 0.8 \text{ L}\cdot\text{d}^{-1}$.

Daily total *ad libitum* water intake ($0.29 \pm 0.1 \text{ L}\cdot\text{MJ}^{-1}$) in the present study was consistent with guidelines from the National Research Council (US) (26) that suggest daily water intake requirements of $0.24 \text{ L}\cdot\text{MJ}^{-1}$ ($1.0 \text{ mL}\cdot\text{kcal}^{-1}$) for average energy expenditure and environmental exposure and $0.36 \text{ L}\cdot\text{MJ}^{-1}$ ($1.5 \text{ mL}\cdot\text{kcal}^{-1}$) for higher levels of physical activity, sweating and solute load and is similar to measured water loss ($0.28 \pm 0.03 \text{ L}\cdot\text{MJ}^{-1}$) in healthy young men observed in summer in North West Europe with a temperate climate (40). Expressing daily fluid intake relative to body mass, the runners in the present study ingested $42.6 \pm 13.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$ ($68.4 \pm 14.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$ when taking the water content of food into consideration). Kirsch and von Ameln (21) reported that 13 European long distance runners (median body mass of 64.0 kg), training in similar environmental temperatures ($18\text{--}24^\circ\text{C}$; $20\text{--}40\%$ RH), maintained daily fluid balance with a mean fluid intake of $33 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$. Runners in the present study probably required greater daily fluid intake due to a greater training volume as the runners in the study by Kirsch and von Ameln (21) trained just once a day. Drinking behaviours observed in the present study are similar to the findings of Adolph and Dill (1) (i.e., “ingestion lagged considerably behind output during exercise and was largely made up at meals”) and are consistent with the ACSM Position Stand on Exercise and fluid replacement (4). Thus in the present study, elite Kenyan endurance runners seemed to perfectly adjust daily fluid intake to daily fluid needs by relying on their sensation of thirst and eating and drinking habits alone. However, it is undetermined whether this would hold under increased heat stress.

During training runs, the athletes did not consume fluid. This was likely the result of short duration training runs that typically lasted less than or about 1 h (Table 2) and therefore did not require fluid replacement (10). During longer duration exercise, Noakes et al. (28) have proposed that an *ad libitum* fluid intake strategy is all that is necessary to offset any negative effects of dehydration. This has since been corroborated in several studies that have reported no benefit of drinking high rates of fluid compared to *ad libitum* (e.g., (33)). The current ACSM Position Stand for exercise and fluid replacement (4) suggests fluid intake should be *ad libitum* from 0.4 to $0.8 \text{ L}\cdot\text{h}^{-1}$ with the lower value for slower, lighter individuals competing in cooler environments, and, the higher value for

faster, larger individuals competing in warmer environments. This agrees with fluid intake guidelines previously proposed by The International Marathon Medical Directors Association (29) that suggests athletes should consume fluid as dictated by thirst (i.e., *ad libitum*) but not more than 0.4 to $0.8 \text{ L}\cdot\text{h}^{-1}$. These guidelines have also been adopted by other organizations such as USA Track and Field (8). Similarly, the International Consensus Guidelines for the Prevention of Exercise-Associated Hyponatraemia invoke the same advice (19).

Diet composition and energy balance. The diet fulfilled current recommendations for carbohydrate and protein intake for endurance athletes, typically $55\text{--}58\%$ ($6\text{--}10 \text{ g}\cdot\text{kg}^{-1} \text{ BM}\cdot\text{d}^{-1}$) of energy from carbohydrate, and $12\text{--}15\%$ ($1.2\text{--}1.4 \text{ g}\cdot\text{kg}^{-1} \text{ BM}\cdot\text{d}^{-1}$) of energy from protein (3). In contrast, fat intake was very low ($6.6 \pm 1.0\%$, $0.8 \text{ g}\cdot\text{kg}^{-1} \text{ BM}\cdot\text{d}^{-1}$) and did not comply with current recommendations, i.e., typically $> 15\%$ of energy from fat (3). Such a low fat diet may compromise intramuscular triacylglycerol concentration with presently unknown consequences in endurance exercise performance (38). Nevertheless, contrary to previous observations of elite Kenyan endurance runners training prior to major competition (17,30), the subjects in the present study appeared in energy balance during the recording period. It is likely this was due to the comparatively lower weekly training distance achieved during the present recording period compared to the earlier studies; this is illustrated by the lower physical activity level (i.e., energy expenditure/BMR) in the present study (2.1 vs 2.3 (30) and 2.3 (17)).

Mean dietary K intake was significantly different from mean K loss in sweat and urine over a 24-h recording period (3812 ± 489 vs $2346 \pm 846 \text{ mg}\cdot\text{d}^{-1}$; $P < 0.001$) equivalent to a mean difference of $1466 \pm 846 \text{ mg}\cdot\text{d}^{-1}$. The finding of excess K intake when compared to K loss in sweat and urine is likely due to faecal losses, which was unfortunately not measured in the present investigation. Holbrook et al. (20) reported that although the range of Na faecal excretion was low in 28 healthy adults investigated over a 1-yr period ($10\text{--}125 \text{ mg}\cdot\text{d}^{-1}$), the range of K faecal loss was greater ($112\text{--}846 \text{ mg}\cdot\text{d}^{-1}$). The mean dietary intake of Na in the present study was similar to that in the study by Holbrook et al. (20) (3245 vs $3000 \text{ mg}\cdot\text{d}^{-1}$) whereas, K intake in the present study was substantially greater (3812 vs $2800 \text{ mg}\cdot\text{d}^{-1}$). This suggests subjects in the present investigation may have excreted more K in faeces than reported previously (20) and thus may explain the apparent K excess, however, this remains to be determined. In contrast, Na intake was not significantly different from Na loss (3245 ± 901 vs $3254 \pm 1070 \text{ mg}\cdot\text{d}^{-1}$; $P = 0.975$). Thus, elite Kenyan endurance runners do not require additional electrolyte supplementation above habitual dietary intake. This is further supported by early work by Pitts et al. (31) who noted that subjects marching in the heat did not require further salt supplementation above that consumed in their diet and is consistent with the new ACSM

Position Stand (4). It is acknowledged however that the determination of sweat electrolyte concentrations may have been effected by the collection method used in the present investigation as it has generally been observed that local sweat electrolyte concentration using the enclosed patch technique is higher than measurements using the whole-body technique (e.g., (22)). Nevertheless, sweat [Na] and [K] in the present investigation (Table 1B) are comparable to values reported in heat acclimatised individuals (11,34).

Training load. Training distance achieved over the 5-d recording period (81.7 ± 11.3 km) was substantially lower than that typically reported albeit over a 7-d training period in other elite endurance runners (e.g., (27)). This was because athletes were in a 10-d taper phase of their training cycle as the investigation was undertaken 1 wk prior to the Kenyan national trials for the 2005 IAAF Athletics World Championships. Nevertheless, the 5-d training distance achieved in the present investigation is similar to values reported (27) for elite Kenyan athletes preparing for major competition prior to the cross-country season in Kenya ($80\text{--}100$ km·wk⁻¹). Indeed, similar to the current study, Noakes (27) reported that during this period, athletes typically ran an easy run (30 min) each morning, with the final 800–1600 m being run at race pace, two interval training sessions per wk and two long runs (60 min). This resulted in ~25% of the training volume run at race pace or greater; this value is comparable to the weekly training load in the present investigation (i.e., 26% of total weekly training time spent > 80% HR_{peak}). Indeed, training sessions in the present study were on average characterised by moderate to low intensity running interspersed with high intensity running such as interval training (Table 2). This was also reflected in lower mean peak T_{re} during morning and afternoon runs (Fig. 1) compared to interval training sessions ($38.6 \pm 0.9^\circ\text{C}$ vs $39.5 \pm 1.8^\circ\text{C}$, respectively). These

findings corroborate previous investigations that indicate low to moderate intensity training accounts for the majority of training time in endurance athletes (e.g., (15)). Typical examples of this type of training were the morning short (completed by middle-distance runners) and medium training runs (equivalent to a short run for long-distance runners) as well as afternoon runs (all runners). These runs typically served as a warm-up (for interval training) and/or a recovery run that usually compromised periods of slow and fast running with hopping and bouncing exercises that resulted in a relatively low mean speed for the training distance achieved (Table 2). Whether the findings of the present investigation apply to elite Kenyan endurance runners during a period of greater training load/intensity is unknown and remains to be determined.

CONCLUSIONS

In conclusion, these results suggest habitual *ad libitum* fluid and food intake is adequate to maintain hydration and electrolyte balance on a daily basis in elite Kenyan endurance runners under mild ambient conditions and during a 10-d taper phase. The drinking and eating habits of the elite Kenyan endurance runners in the present study corroborate the new ACSM guidelines for fluid and electrolyte replacement (4). However, this is a narrow sample of athletes and our findings may not apply to all athletes, in all sports or training scenarios.

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